Project Title: Identifying Local Factors Which May Exacerbate Coastal Acidification in the Tillamook Estuary (Oregon).

EPA Region: Region 10

Regional Technical Contact: Rochelle Labiosa, Water Quality Standards Unit

Regional Manager's Name and Signature:

Angela Chung, Water Quality Standards Unit Manager Date

ORD Principal Investigator (PI): Dr. Cheryl Brown, Research Oceanographer, Western Ecology Division

ORD Project Officer (PO)/Contracting Officer's Representative (COR): Christina Folger, Western Ecology Division

ORD Manager's Name and Signature:

Ted DeWitt, Pacific Coastal Ecology Branch Chief, Western Ecology Division *Date*

Regional Science Liaison (RSL) Contact:

Bruce Duncan *Date*

Anticipated Start Date: Feb 1, 2017

Anticipated Completion Date: August 1, 2018

Funding Requested: $106,000

Anticipated Funding Mechanism: Existing IAG with USGS-Menlo Park and BPA contract with University of California-Santa Barbara

ORD Research Program:
SSWR 4.02B: Ecosystem Response and Recovery (focus on Nutrient Enhanced Coastal Acidification); ACE CIVA-2.1 Assessing impacts of climate stressors on near coastal species; SHC 2.61 Task 5 (Coordinated Case Studies)

PROJECT SUMMARY

Statement of Problem: Current understanding of coastal carbonate chemistry variability is in its infancy; estimates of how coastal water chemistry will change through the next century are predominantly based on a decoupled understanding of anthropogenic climate change (i.e. CO_2 entrainment and associated acidification) and cultural eutrophication. Recently, the potential importance of synergies between "classical" ocean acidification and eutrophication of coastal waters in mediating nearshore water column carbonate chemistry has gained interest in the scientific and aquaculture communities. The frequency, magnitude, and duration of coastal carbonate chemistry variability are thought to be affected by multiple drivers of both natural and anthropogenic origin. The anthropogenic component of this variability is not well characterized at scales relevant to nearshore biota, yet it is essential to understand for resource managers and policy makers. We propose to quantify the role of watershed and oceanic factors on carbonate chemistry in the Tillamook Estuary.

Research Approach: Study objectives will be met through a combination of short-term sensor deployments (with carbonate chemistry, nutrient, and water quality sensors) and research cruises in Tillamook Estuary, OR. During these field studies, water samples will be collected for nutrients, carbonate chemistry, and isotopes of nutrients, carbon, oxygen, and organic matter. The link between nutrient/organic matter delivery and carbonate chemistry variability will be investigated by tracing nutrient and organic matter delivery from distinct natural and anthropogenic end-members to the study sites through isotopic analyses. Mixing models of these isotopes will be used to partition the relative contribution of oceanic, wastewater treatment facility effluent, agricultural sources, and other watershed sources (e.g., red alder trees). Stoichiometric models of nutrient assimilation, primary production, and respiration will be used to quantify the fluxes of organic matter and dissolved inorganic carbon through the biological communities as a result of anthropogenically-derived inorganic nitrogen. These fluxes will be superimposed on continuous data sets of carbonate chemistry variability obtained via autonomous instrumentation at each study site to separate the magnitude, duration, and frequency of variability in pH and Ω resulting directly from anthropogenic nutrient/organic matter addition and assimilation.

Anticipated Results and Regional Impact: This project will improve our understanding of how anthropogenic nutrient and organic matter delivery to coastal areas impacts pH and carbonate chemistry variability, and quantify the magnitude and frequency of resultant departures from natural conditions. Quantitative data on these departures is currently non-existent, yet necessary for 303(d) listing decisions and development of ecological management plans. In addition, assessing the departures above the natural condition and whether pH is refined enough to capture carbonate chemistry dynamics and impact on sensitive species will help policymakers to assess the need for additional water quality standards beyond pH to protect species from the harmful effects of ocean acidification. In Region 10, recent litigation on 303(d) listing decisions and a national petition to alter water quality standards to protect ecosystems from the effects of ocean acidification have highlighted the need for further investigation into the variability in carbonate chemistry and the source of that variability. This work will prove essential to informing regional decision making in these Clean Water Act programs on these issues.

Anticipated Final Products: This study will demonstrate approaches to identify local factors influencing carbonate chemistry in estuarine habitats. Results will be published in the peer-reviewed primary literature and presented at relevant scientific and community meetings. A webinar will be conducted to discuss study results and implications with state and tribal government environmental managers.

PROPOSED PROJECT SCOPE

Background: Ocean acidification (OA) is defined as the ongoing decrease in pH of the world's oceans as a result of uptake of anthropogenically-derived carbon dioxide (CO_2) from the atmosphere. Global surface ocean pH levels have decreased by ~0.1 units since the Industrial Revolution, with a further decrease of 0.3-0.4 units projected by the year 2100[1]. This decrease in oceanic pH is concurrent with decreased saturation states (Ω) of the biominerals aragonite and calcite, thus making it more difficult for calcifying organisms (e.g. oysters) to form and maintain shells. Recent work has shown that the variability in pH and Ω in coastal systems is much higher than open ocean systems[2]. It varies strongly on short time scales (<24 hours), and at some coastal locations pH declines currently exceed IPCC projections of open ocean pH declines for the year 2100[2,3]. This increased variability in coastal systems is the net result of multiple drivers, including variations in primary production and respiration, river runoff, cultural eutrophication, oceanic upwelling, and atmospheric exchange[1,4,5] The sum of the impact of these processes on pH and the carbonate system is referred to as coastal acidification. Our understanding of how these processes interact in the coastal environment is hindered by the lack of time series data of carbonate chemistry in shallow, nearshore environments (e.g. estuaries, seagrass beds, shellfish beds). This makes predictions of how coastal systems will be impacted by climate change problematic, yet these predictions are extremely important due to the ecological, cultural, and economic importance of these ecosystems. Decreases in pH and Ω have been shown to impair metabolic and physiological mechanisms in coastal marine organisms[3,6,7]. For example, commercial shellfish hatcheries in Oregon, Washington, and British Columbia have reported instances of large scale larval failures due to coastal upwelling of high pCO_2 and low Ω waters used in the larval rearing process[2,8]. Therefore, we propose to characterize the variability of pH and carbonate chemistry in an estuary exposed to both episodic upwelling and elevated watershed nutrient input, and quantify how the interaction of these processes affect pH and Ω variability in shallow, nearshore habitats important for many coastal species. The study sites will be located in the vicinity of shellfish beds (including oysters). We hypothesize that sites exposed to elevated watershed nutrient and organic matter delivery will have more variable pH and carbonate chemistry, as well as shifts in net ecosystem metabolism and baseline pH levels.

Project History: This project will build upon the methodology and findings of a 2015 Region 10 RARE project, entitled "Toward a unified understanding of coastal acidification processes in Puget Sound." In the 2015 project, we demonstrated methodologies for monitoring carbonate chemistry in shallow estuarine habitats and identifying drivers of carbonate chemistry variability. The proposed project in Tillamook Estuary (Oregon) would build upon the lessons learned from this previous RARE project.

This proposed study also benefits from previous research by ORD within the Tillamook estuary, a National Estuary Program (NEP) estuary within the Tillamook Estuaries Partnership (TEP) as well as data collected by TEP. For example, ORD has demonstrated that elevated nutrient levels occur in Tillamook Estuary tributaries/sloughs and that an elevated nitrogen isotope ratio of nitrate signature occurs in the vicinity of agriculture activities and wastewater point source inputs; however, impacts if any have not been quantified. This distinctive isotope ratio will facilitate the identification of the role of watershed nutrient inputs on carbonate chemistry. In addition, we have developed and applied a statistical tool which identified the incursion of oceanic low oxygen events into portions of the estuary[9]. In 2016, ORD's Western Ecology Division is initiating a case study within the Tillamook estuary focused on the role of climate change on influencing water quality and ecosystem services (combined SSWR4.02B and SHC 2.61 Task 5 (Coordinated Case Studies), Subtask 2 (Pacific NW Case Study). Components of this case study will include the development of a linked watershed-estuarine

biogeochemistry model as well as field studies focused on nutrient and pathogen source tracking. This RARE project will be embedded within this Case Study and will benefit from data collected as part of the Case Study. This RARE project will allow us to include advanced stable isotope techniques (not available within ORD) to tease out local watershed contributions to acidification in the estuary. Comparative analyses with predicted loading of nutrients as determined by the USGS SPARROW model will be conducted and will expand the applicability of the Tillamook results to other geographic areas.

Research Objectives: The objectives of this project are to: 1) characterize the variability of carbonate chemistry (e.g. pH and Ω) in shallow, subtidal areas of an open-coast estuary exposed to episodic upwelling and elevated watershed nutrient/organic matter inputs, 2) identify natural and anthropogenic sources of nutrients and organic matter delivered to these habitats via stable isotope analyses, and 3) quantify the departure in natural pH and carbonate chemistry variability due to production/respiration of anthropogenic nutrients and organic matter. These objectives will be met through a combination of autonomous sensor deployments and research cruises in Tillamook Estuary, OR. During these field studies, water samples will be collected for sensor validation, nutrients, carbonate chemistry, and isotopes of nutrients and organic matter. This project will improve our understanding of how anthropogenic nutrient and organic matter delivery to coastal areas impacts pH and carbonate chemistry variability, and quantify the magnitude and frequency of resultant departures from natural conditions. Quantitative data on these departures is currently non-existent, yet necessary for 303(d) listing decisions and development of ecological management plans. In addition, assessing the departures from the natural condition, and whether pH is refined enough to capture carbonate chemistry dynamics and resultant impact on sensitive species, will help policymakers, including Region 10 water quality standards coordinators for our coastal states, to assess the need for additional water quality standards beyond pH to protect species from the harmful effects of coastal acidification. Recent research has shown that coastal ecosystems in the Pacific Northwest will be the first in the U.S. to be exposed to ocean/coastal acidification, and its communities which rely on shelled molluscs are currently at risk from OA impacts[10]. This combination makes the Pacific Northwest a highly sensitive region with respect to OA, from both ecological and economic perspectives. Therefore, not only is this project relevant for estuarine ecosystem management and regulation in the region, it will also serve to inform other regions of the U.S. of expected future coastal conditions and processes. In addition, this study will add valuable baseline knowledge of estuarine carbonate chemistry variability in ecologically and economically important habitats, at spatio-temporal scales relevant to individual organisms. As a result of the poor characterization of coastal carbonate chemistry variability, the majority of acidification effects studies (e.g. organism response) ignore this variability, and instead use static water chemistry treatments. The utility of this approach has recently been called into question[11]. Therefore, our proposed study will provide a new understanding of coastal carbonate chemistry variability experienced by nearshore biota for both 1). Better management and regulatory decision making, and 2). Future ecological and chemical experiments reliant on accurate characterization of nearshore conditions.

Research Approach: Previous research experience in the Tillamook Estuary has aided in identifying this location as being exposed to episodic oceanic upwelling of deep, high CO_2 waters, as well as elevated watershed nutrient delivery. The combination of these environmental drivers allows for our investigation of nutrient-enhanced acidification processes, and how these processes impact the natural pH and carbonate chemistry regime.

Two field study sites will be selected in shallow, subtidal seagrass beds in the vicinity of shellfish beds which have been previously shown to be exposed to a wide salinity range, in order to ensure the sites are subject to both terrestrial/riverine and oceanic influences. The sites will be chosen to

minimize habitat differences between them (e.g. depth, sediment type). One site will be located in the southern portion of the estuary, close to the influence of the Tillamook and Trask rivers. The second site will be located closer to the mouth of the estuary with more oceanic influence. Each study site will be instrumented with YSI 6000 Series sondes, Satlantic ISUS NO_3 sensors, and SAMI (pH and pCO_2). This instrumentation will provide 15-minute time resolution observations of temperature, salinity, depth, chlorophyll, dissolved oxygen, pH (NBS), nitrate, pH (Total), and pCO_2. Instrumentation will be deployed concurrently at both study sites for multiple extended periods (> 2 months) during the dry and wet seasons, allowing for comparison of pH and carbonate chemistry variability between sites of differing oceanic and riverine influence over tidal to seasonal time scales. In addition, research cruises will be conducted along riverine-oceanic transects during the year to elucidate the factors influencing carbonate chemistry at the bay scale. Grab samples will be collected at both sites and during the cruises for pCO_2, TCO_2, dissolved inorganic nutrients, chlorophyll, TSS, and isotopes of nitrogen (NO_3 and NH_4), carbon (dissolved inorganic carbon (DIC)), and organic matter (dissolved and particulate).

The link between nutrient/organic matter delivery and carbonate chemistry variability will be investigated by tracing nutrient and organic matter delivery from distinct natural and anthropogenic end-members to the study sites through isotopic analyses. Mixing models of these isotopes will be used to partition the relative contribution of oceanic upwelled, wastewater treatment facility effluent, agricultural sources, and other watershed sources (e.g., red alder trees). Tissue samples of primary producers (e.g., seagrass, macroalgae, phytoplankton) will be analyzed for $\delta^{15}N$ and $\delta^{13}C$ at the Integrated Stable Isotope Research Facility (ISIRF) at the Western Ecology Division ORD. Water samples from end members and the study sites will be analyzed by ISIRF for coupled $\delta^{15}N$ and $\delta^{18}O$ nitrate analysis and by USGS-Menlo Park for $\delta^{15}N$ ammonium analysis, DIC, DOM, and O_2 isotopes. Dissolved inorganic nutrients will be analyzed by the MSI Analytical Laboratory at UCSB. Stoichiometric models of nutrient assimilation, primary production, and respiration will be used to quantify the fluxes of organic matter and DIC through the biological communities as a result of anthropogenically-derived inorganic nitrogen. These fluxes will be superimposed on continuous data sets of carbonate chemistry variability obtained via autonomous instrumentation at each study site to separate the magnitude, duration, and frequency of variability in pH and Ω resulting directly from anthropogenic nutrient/organic matter addition and assimilation. This technique will also allow us to also back-calculate the "natural" pH and Ω variability at the study sites in the absence of elevated nutrients and organic matter.

Project Team's Roles and Responsibilities: Dr. Rochelle Labiosa is the R10 Technical Manager and will provide technical guidance. Dr. Bruce Duncan, R10 RSL, will participate in regular check-ins to ensure that the project is tracking milestones related to the RARE program, including program reporting. Dr. Cheryl Brown is the ORD Principal Investigator and is responsible for project management and preparation of quality assurance documents, communication with Region 10 and other technical staff, technical guidance of the project and management of budget. Dr. Cheryl Brown and Stephen Pacella will be responsible for study design, quality assurance, data management and data analysis, and producing research products with input from Dr. Rochelle Labiosa and Dr. Megan Young. Assistance with field work and instrumentation will be provided by TChris Mochon Collura and Jim Kaldy (both from WED). Lisa Phipps (Executive Director of Tillamook Estuaries Partnership, see attached letter of support) will be a collaborator on this project providing technical guidance on study design, providing broader context for study results based upon other studies conducted by the TEP, and assisting with outreach to stakeholders. Dr. Megan Young will oversee isotope analyses performed by USGS-Menlo Park and quality assurance of these data and Christina Folger will be the Project Officer on the IAG with USGS.

Research Results, Products, and Communication Plan: Results will be disseminated in various manners to maximize their scientific and management values. We envision this project will be useful for EPA Region 10 decision makers and state natural resource managers (e.g., verifying or updating current water quality standards; developing future response strategies; 303(d) listing decisions for coastal waters), the aquaculture industry (e.g. planning adaptation and mitigation strategies), land use planning and management (e.g., future planning development), as well as the scientific community (e.g., characterizing drivers of nearshore carbonate chemistry variability; experimental design). Results will be published in the peer-reviewed primary literature and presented at relevant scientific and community meetings. A webinar will be conducted to discuss implications with state and tribal government environmental managers after the publication is released.

Proposed Budget: We are proposing a one year project and are requesting $106,000. The majority of budget ($88,000) will be used to fund an existing IAG with USGS Menlo Park established for our current RARE project. This collaboration with the USGS will allow us to obtain stable isotope analyses currently unavailable within ORD which will aid in the tracking of nutrient and carbon and identifying local causes of acidification. The remaining funds will be used to fund nutrient analyses (funding of $10,000 through an existing Blanket Purchasing Agreement with UCSB) and for expendable supplies associated with sampling (estimated to be $8,000 for filters, reagents for carbonate chemistry instrumentation, sampling containers).

Field work is scheduled for spring transition, dry season (May-Sept), fall, and winter. After each field sampling, water samples will be processed and analyzed and data from instrumentation will be reviewed to ensure they meet quality assurance metrics outlined in the QAPP and data will be analyzed. A timeline for proposed study is as follows:

Milestone	**Month**
Revise QAPP and process funding paperwork	February 2017
Plan field studies, procure supplies, submit progress report	March 2017
Conduct field work focused on spring transition, dry season, fall, and winter	April 2017-February 2018
Submit progress report	September 2017
Submit annual report	February 2018
Finalize data analysis and write up results	February – August 2018
Submit final report	August 2018

Project Management: Dr. Cheryl Brown will have overall responsibility for managing this project. Dr. Brown will keep the Region 10 RSL informed on the status and progress of this research through monthly conference calls. The proposed activities are similar to data collection activities covered by QAPP from our previous RARE Project, and the QAPP will be revised as needed. Reporting results of this research will be through the project briefings, reports, peer-reviewed publications, and presentations at meetings to transfer the outcomes of the research. All products will undergo a technical and quality assurance review and be cleared through STICS prior to publication and all data will be uploaded into Science HUB for dissemination to the public. With the assistance of appropriate Region 10 staff, outreach to representatives Tillamook Estuaries Partnership will be conducted to convey progress on the research. Outreach activities will also be coordinated with Rochelle Labiosa, the Region 10 RSL, and with Lisa Phillips (Tillamook Estuaries Partnership). Other outreach activities may include lab and field site visits.

Letters of Support

Tillamook Estuaries Partnership
A National Estuary Project

613 Commercial Street, PO Box 493, Garibaldi, OR 97118 Phone (503) 322-2222 Fax (503) 322-2261
The Tillamook Estuaries Partnership is a non-profit organization dedicated to the conservation and restoration of Tillamook County's estuaries and watersheds in their entirety.

March 11, 2016

Re: EPA's Regional Applied Research Effort (RARE) entitled "Identifying Local Factors Which May Exacerbate Coastal Acidification in the Tillamook Estuary (Oregon)."

To Whom It May Concern:

I am writing in support of the above-referenced application focused on advancing our ability to better evaluate factors influencing acidification conditions within the estuary (e.g., separating the role of oceanic conditions, versus watershed by location within the estuary).

Tillamook Estuaries Partnership (TEP) is a 501(c)(3) non-profit organization and part of the National Estuary Program, created through the Clean Water Act and the Tillamook Bay has been designated as a "bay of national significance". The four key areas that we focus on are 1) key habitat loss, 2) water quality, 3) minimizing flood impacts, and 4) citizen involvement. We have a keen interest in the Tillamook Bay estuary and how watershed processes affect this estuary. In 2013, TEP commissioned the Oregon Climate Change Research Institute to complete a report that described the past climate of the watershed, projected future climate change over the next century, and suggested possible impacts. As a priority of the US EPA, our oversight agency, TEP is interested in gathering any information on climate change that can assist us in on-the-ground project development. As a follow-up to that effort, TEP secured funds through EPA's Climate Ready Estuaries program to implement a Vulnerability Assessment this year. We are also involved in convening a larger effort to look at the viability of a coast-wide OA monitoring network.

We have gathered data on water quality for the past 20 years and hope that this information can help inform the past conditions as this proposed application looks to how climate change will affect future water quality parameters. We are excited about the potential uses of the information gathered from this proposed project and how it can be applied to actual work on the ground.

Region 10 has listed Ocean Acidification as a high priority issue and this project would align well with a developing ORD Research Program case study and of which we are also a supporting partner.

Tillamook Estuaries Partnership
A National Estuary Project

613 Commercial Street, PO Box 493, Garibaldi, OR 97118 *Phone (503) 322-2222 Fax (503) 322-2261*
The Tillamook Estuaries Partnership is a non-profit organization dedicated to the conservation and restoration of Tillamook County's estuaries and watersheds in their entirety.

I writing in support of the above referenced application focused on advancing our understanding of the physical oceanography of Oregon estuaries.

We are happy to support this project both by this letter and to provide any assistance as seems appropriate.

We strongly urge you to support this effort. If you have any questions, please feel free to contact me at 503-322-2222 or by email at lphipps@tbnep.org.

Sincerely,

Lisa Phipps, Executive Director

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